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METHODS TO INVESTIGATE FERTILIZATION AS A MEANS TO IMPROVE GROWTH AND SUGAR YIELD OF SUGAR MAPLE

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ABSTRACT: In a randomized block experiment, NPKCa fertilizers were applied annually for 5 years to a mature sugar maple (*Acer saccharum* Marsh.) woodlot in southern Ontario. Trees selected from 3 crown classes were fitted with dendrometer bands, tapped for sap and analyzed for foliar starch and nutrients and sap nutrients. Crown classes responded differently to the fertilizers. Trees which responded significantly in diameter growth did not respond the most in sugar yield. Effects of the fertilizer treatments on sugar yield were shown to be significant when the area of crown overlap of competing trees was subtracted from the crown area of crop trees. Foliar analysis and DRIS showed which nutrients were in demand after fertilizer applications. Sap analysis showed significant relations between sap nutrients and between sap nutrients and diameter growth. Starch analysis showed significantly higher foliar starch concentrations after potassium fertilization than after other fertilizer treatments.

INTRODUCTION

Our knowledge for increasing the sugar output of individual sugar maple trees (*Acer saccharum* Marsh.) has not advanced nearly as fast as other developments in the maple syrup industry (2,3). This is because most research studies have been concerned with collecting, processing and marketing maple syrup, and few studies have been concerned with the physiology of the sugar maple tree or its nutritional needs (4-11).

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Nutritional studies have been limited because of the difficulties of managing sugar maple growing in woodlots which have had many conflicting uses (12,13). These conditions have been exacerbated by the exacting site demands of sugar maple, its great shade tolerance, and its prolific seeding habit (14), resulting in overstocked stands which make experimental work difficult and costly. Examination by the authors of many sugar maple woodlots in southern Ontario, showed that in overstocked stands growing under poor site conditions, the intense competition leads to slow growth, poor quality timber and disease (5,15).

Sugar maple would be less difficult to manage if conflicting uses for the same woodlot could be avoided. For hardwood lumber production, thinnings throughout the stand are usually required to remove unthrifty trees and to train crop trees (6). For maple sap production, however, consideration should be given to thinning and fertilizing around crop trees only (12,13), leaving the rest of the stand as cover for wildlife and to prevent soil erosion. To test this idea, a convenient woodlot of mature sugar maple in a maple sap production area was chosen to determine the effect on maple sap production of increasing the crown areas of crop trees by fertilization after defective trees had been removed by the owner of the woodlot. The intention was also to test methods of monitoring the response of the fertilizers and predicting further fertilizer needs.

MATERIALS AND METHODS

Study Area: The study area was in Flos township, southern Ontario, near Elmvale (44°33'N, 79°52'W), on a "brunisol", a loamy sand of the Tioga series (16), with variable calcium content. The Elmvale stand had 558 trees/ha, mostly sugar maple, with a few other broad-leaf species and some conifers. About 70% of the sugar maple were 25-50 cm diameter at 1.3 m. Trees 50+ cm diameter were 100+ years old. The older trees had asymmetrical crowns due to uneven competition. Heavy branches often split from these crowns during ice-storms, in some rare instances leaving only one-half the tree still standing. The study included 45 crop trees evenly divided among dominant, codominant and intermediate crown classes over approximately 1 hectare (Table 1).

Field Experimentation and Chemical Analyses: Analysis of the upper 18 cm soil showed 0.22% total N, 13 ppm available P, and ppm exchangeable K 62, Ca 1501, Mg 82. Soil pH was 6.4 at a depth of 17 cm.

The basal area at 1.3 m of all trees above 10 cm diameter was calculated from diameter measurements on the 45 plots (Table 1) and on each plot, the basal area of the tapped tree was shown as a ratio of the total basal area on the plot to measure the relative competition on each plot to the tapped tree. The diameter growth of each tapped tree was also measured by a dendrometer band (17) at 1.3 m. The crown area of tapped trees was calculated using Sheppard's device (18). Photos were taken of all tapped trees from which silhouettes were drawn to study branch configuration and crown competition of individual trees. The upper crown foliage of tapped trees was sampled in mid-July (using a 12-gauge choke bore shotgun with a telescopic sight) to be analyzed for nutrient concentration (19,20) and starch (21,22). Foliar nutrient concentration data were combined with growth measurements from dendrometer bands to calculate DRIS indices to determine limiting nutrients (23,24,25).

Granulated fertilizers were broadcast in a swath 5.9 m wide around tapped trees in late spring annually in a randomized block design from 1976 to 1980 inclusive (Table 1). The dosage of fertilizers was guided by the results of a previous experiment in fertilizing sugar maple (unpublished) on a Tioga sand in which a significant response of 48% increase in diameter growth was obtained with NPMg fertilizer at 300 kg/ha. In the Elmvale experiment, the fertilizers applied in kg/ha were: potassium chloride at 224, triple superphosphate at 448 and calcium nitrate at 674, in combination with urea at 224 in the following treatments: a/ U_{224} + KCl_{224}; b/U_{224} + TSP_{448}; c/U_{224} + CaN_{674}; d/U_{224} + TSP_{448} + KCl_{224}.

The response to the fertilizer treatments was measured by changes in: *i)* tree diameters, *ii)* foliar and sap nutrient levels (20,26), and *iii)* sugar concentration and yield (11,20). The sugar yield was related to crown size and trunk diameter, and was calculated from sugar concentration and sap volume using Rule 87.2 of the Maple Sap Producers' Manual (3).

The maple sap was collected in 8.5-litre buckets and its volume was measured early in the morning for the previous night's sap flow and late in the afternoon for the current day's flow, from early March to mid-April. To accomplish this, holes 1.3 cm in diameter were drilled 7.6 cm deep into the crop trees at a height of 1.3 m. A 520 g paraformaldehyde pellet was placed in each hole to control microbial

TABLE 1

Location, Size and Treatment of Tapped Trees in a Randomized Block Design.

Rep. No.	Plot No.	Treatment	Tree	Dist.	DBH
1	1	NK	D-1	24	46.9
			C-16	15	42.5
			I-31	8	28.4
	2	Control	D-2	8	48.9
			C-17	18	43.3
			I-32	8	32.2
	3	NCa	D-3	27	43.5
			C-18	11	40.1
			I-3	18	28.8
	4	NPK	D-4	11	46.3
			C-19	6	37.8
			I-34	15	28.0
	5	NP	D-5	11	42.8
			C-20	23	36.2
			I-35	12	28.4
2	6	NCa	D-6	2	49.7
			C-21	12	40.9
			I-36	11	29.7
	7	Control	D-7	9	42.7
			C-22	15	40.8
			I-37	17	32.7
	8	NPK	D-8	15	50.7
			C-23	11	41.2
			I-38	5	28.4
	9	NK	D-9	6	48.7
			C-24	11	38.7
			I-39	12	29.8
	10	NP	D-10	11	48.8
			C-25	11	35.8
			I-40	5	26.8
3	11	NK	D-11	15	47.8
			C-26	6	36.6
			I-41	9	28.7
	12	Control	D-12	9	49.8
			C-27	20	41.7
			I-42	18	29.7
	13	NPK	D-13	12	47.7
			C-28	11	41.2
			I-43	11	30.3
	14	NP	D-14	15	50.8
			C-29	36	42.3
			I-44	6	33.4
	15	NCa	D-15	30	47.9
			C-30	21	35.8
			I-45	33	31.4

D - Dominant tree DBH range 42.7 to 50.7 cm
C - Codominant tree DBH range 35.8 to 43.3 cm
I - Intermediate DBH range 28.4 to 33.4 cm
Dist. - distance from tapped tree to plot centre in metres. Each tapped tree is also the centre of a sub-plot 5.9 m in radius so that the area on each sub-plot is always the same.

activity (27). Spiles were placed in the drilled holes to support the buckets for sap collection. The buckets were sealed at the top and linked by polyethylene tubing to overflow buckets on the ground. Sap volumes over 1 litre were measured by a rule calibrated to the collection buckets, and volumes under 1 litre were measured by 3 different-sized graduated cylinders. After the sap was stirred, a small vial was filled with sap for the twice-daily determination of sugar concentration using a temperature-compensating refractometer at 20C (20) in a mobile heated laboratory on the study area. Photos were taken of all tapped trees and silhouettes were drawn from the photos to relate configuration of crowns and branching habits to sugar yield. Sap samples were analyzed for nutrient content prior to and after bud break.

RESULTS

Diameter Growth of Crop Trees: Measurements of diameter changes at 1.3 m by dendrometer bands (17) showed the crown classes responded differently to the fertilizers (Table 2). Variance ratios and "t-tests" showed diameter changes for dominant and codominant crown classes only were significant. Dominant tapped trees (avg. DBH 49.5 cm) treated with U_{224} + TSP_{448} increased in diameter 33% more than control dominants, while those treated with U_{224} + KCl_{224} decreased 32% in diameter growth below the controls. Codominant trees (avg. DBH 41.4 cm) treated with U_{224} + CaN_{674} increased 48% more in diameter than control codominants. Intermediate tapped trees (avg. DBH 41.4 cm) treated with U_{224} + TSP_{448} + KCl_{224} increased 16% more in diameter than control intermediates.

Some of the most important treatment comparisons are shown in Table 3. There were inconsistent relations between replications among treatments. It should be noted the U_{224} + KCl_{224} treatment resulted in less diameter growth in treated dominants than in control dominants.

Sugar Yield: Total sugar yield and average sugar concentration based on one tap per tree regardless of diameter were in the descending order: dominants, codominants, intermediates (Tables 4,5 and 6). Analysis of variance showed treatments had a significant effect at the 5% level on sugar yield but not upon sugar concentration (Table 7). Dominant trees treated with U_{224} + TSP_{448} + KCl_{224} had sugar yields 27% and 22% higher than controls in the 4th and 5th years

TABLE 2

Diameter Growth Responses Expressed as a Growth Ratio** of Sugar Maple to Fertilizer Treatments by Crown Classes.

Treatments	1976	1977	1978	1979	1980	1981	6-year average
Dominant Crown Class							
NCa*	459**	462	559	139	338	444	400
NP	883	919	843	335	404	492	646
NK	321	542	485	216	280	363	368
NPK	763	771	680	335	400	520	578
Control	515	833	625	240	299	406	486
Codominant Crown Class							
NCa	968	1159	762	363	403	418	679
NP	344	334	477	200	304	427	348
NK	556	733	804	346	471	578	581
NPK	788	663	669	262	274	359	502
Control	594	482	655	284	359	366	457
Intermediate Crown Class							
NCa	983	1054	940	407	547	745	779
NP	739	1020	867	348	471	610	674
NK	593	572	809	336	443	670	570
NPK	1012	1445	991	424	449	506	804
Control	872	1074	975	387	450	504	710
Averages	693	803	743	308	393	493	572

* NCa = U_{224} + CaN_{674}; NP = U_{224} + TSP_{448}; NK = U_{224} + KCl_{224}; NPK = U_{224} + TSP_{448} + KCl_{224}.

** To make allowances for stem irregularities and the great variation in diameters of tapped trees within crown classes, diameter increases were recorded by dendrometer bands and expressed as growth ratios:

$$\text{Growth Ratio} = \frac{\text{Average diameter increase 1976}}{\text{Initial average diameter 1976}} = .00459$$

This growth ratio was inflated by 10^5 to facilitate statistical analysis. Irregularities in growth are probably due to a forest tent caterpillar infestation in 1977 which was somewhat controlled by aerial spraying of Thuricide 90TS.

TABLE 3

Significant Relative Diameter Responses of Tapped Trees to Fertilizers by Crown Classes.

Analysis of variance		Fertilizer used	Diameter Inc. as % of cont. increase	"t-test" sig.
Source	F-ratio	Dominants		
Replications	31.63**	U_{224}+TSP_{448}	33	3.95**
Treatments	10.71**	U_{224}+TSP_{448}+KCl_{224}	20	2.36*
		U_{224}+KCl_{224}	-32	2.92*
		Codominants		
Replications	10.62**	U_{224}+CaN_{674}	48	2.28*
Treatments	4.63**	U_{224}+KCl_{224}	27	2.44*
		Intermediates		
Replications	19.93**	U_{224}+TSP_{448}+KCl_{224}	18	n.s.
Treatments	1.89	U_{224}+CaN_{674}	10	n.s.

Significance ** = 1%; * = 5%
Note: CaN = $Ca(NO_3)_2$

respectively after treatments were started. The total sugar yield was 11% higher than in dominants having the highest growth increase. Codominant trees treated with U224 + TSP448 had sugar yields 45% higher than controls in the 5th year after the fertilizer treatments were started. The total sugar yield was 36% higher than in codominants having the highest growth increase. Intermediate trees treated with U224 + TSP448 + KCl224 had sugar yields 56% higher than controls in the 4th year after fertilization was started. The total sugar yield was 22% higher than controls.

Sugar concentrations were very much affected by the weather during and between "runs" (2,28). At very low temperatures the sap tended to congeal and readings from small sap samples sometimes showed sugar concentrations 12%±. For the data in Tables 4, 5 and 6, vials of sap from buckets were immersed in a water bath at 20C in a heated mobile field laboratory and refractometer readings made by two operators until an agreeable average concentration was reached for each sample. On three occasions, this method was compared with a spot sampling method from awl perforations (Table 8). In spot sampling, readings of small

TABLE 4

Average Annual Sugar Yields (in grams) and Concentrations (in per cent) of Dominant Trees by Treatments over a 5-Year Period.

	Average sugar yields in grams						
Treatments	1977	1978	1979	1980	1981	Total	Averages
NCa	1344	1072	1387	761	1608	6172	1234
NP	2078	1217	1870	1047	1935	8147	1629
NK	2074	974	1980	867	1871	7766	1553
NPK	2392	1253	2108	1063	2235	9051	1810
Control	2269	1362	2117	831	1827	8406	1681
Totals	10157	5878	9462	4569	9476		7907
Averages	2031	1175	1892	914	1895		1581
	Average per cent sugar concentration						
Treatments	1977	1978	1979	1980	1981	Total	Averages
NCa	1.8	2.3	2.1	2.0	2.6	108	2.16
NP	1.8	2.1	2.0	2.0	2.8	107	2.14
NK	1.7	1.9	2.0	1.9	2.5	100	2.00
NPK	1.9	2.2	2.1	2.3	3.1	116	2.32
Control	1.9	2.3	2.1	2.2	2.6	111	2.22
Totals	9.1	10.8	10.3	10.4	13.6		10.84
Averages	1.82	2.16	2.06	2.08	2.72		2.17

quantities of sap were made in the field while maintaining the refractometer at 20C, and were repeated by two operators until agreement was reached for an average concentration of each sample

Foliar Analysis: In mid-July, 1976, three months after the initial fertilizer application, the average percentage foliar nutrient concentrations in codominant trees was:

	N	P	K	Ca	Mg
Fertilized trees	2.34	0.13	0.53	1.23	0.15
Control trees	2.23	0.12	0.49	1.28	0.16

Concentrations of N,P and K were higher and concentrations of Ca and Mg were lower than controls. An analysis of variance (Table 9) showed direct effects

TABLE 5

Average Annual Sugar Yields (in grams) and Concentrations (in per cent) of Codominant Trees by Treatments Over a 5-Year Period.

	Average sugar yields in grams						
Treatments	1977	1978	1979	1980	1981	Total	Averages
NCa	1204	808	1194	579	1139	4924	985
NP	1631	756	1857	850	1627	6721	1344
NK	1617	853	1530	703	1247	5950	1190
NPK	1602	854	1586	632	1332	6006	1201
Control	1547	1196	1638	637	919	5937	1187
Totals	7601	4467	7805	3401	6364		5907
Averages	1520	893	1561	680	1253		1181
	Average per cent sugar concentration						
Treatments	1977	1978	1979	1980	1981	Total	Averages
NCa	1.7	1.9	1.8	1.8	2.7	9.9	1.98
NP	1.8	2.0	2.0	2.0	2.5	10.3	2.06
NK	1.7	2.0	1.6	1.7	2.7	9.7	1.94
NPK	1.8	2.0	2.0	1.9	2.6	10.3	2.06
Control	1.8	2.1	1.9	2.0	2.4	10.2	2.04
Totals	8.8	10.0	9.3	9.4	12.9		10.08
Averages	1.76	2.00	1.86	1.88	2.58		2.02

of treatments were significant at the 1% level for foliar N and K only. The direct effect of crown classes was significant at the 5% level for foliar P and K, and at the 1% level for foliar Mg. A "t-test" showed foliar N varied significantly from the controls at the 1% level following the NCa treatment and at the 5% level for the other fertilizer treatments. Foliar K varied significantly from the control following the U_{224} + K_{224} treatment only.

Foliar analysis for starch concentrations in the upper crowns of all crown classes of tapped sugar maple made in mid-July, 1976, showed the effects of the fertilizer treatments were significant at 1% level. A "t-test" of percentage starch concentration (Table 10) showed trees treated with U_{224} + KCl_{224} had significantly higher starch concentrations (5% level) than the controls or any other treatment.

TABLE 6

Average Annual Sugar Yields (in grams) and Concentrations (in per cent) of Intermediate Trees by Treatments Over a 5-Year Period.

	Average sugar yields in grams						
Treatments	1977	1978	1979	1980	1981	Total	Averages
NCa	835	628	1152	581	925	4121	824
NP	1097	654	840	552	930	4073	815
NK	893	535	949	442	858	3677	735
NPK	1176	765	1119	548	922	4530	906
Control	906	508	1061	351	872	3698	740
Totals	4907	3090	5121	2474	4507		4020
Averages	981	618	1024	495	901		804
	Average per cent sugar concentrations						
Treatments	1977	1978	1979	1980	1981	Total	Averages
NCa	1.6	2.0	2.0	2.0	2.3	9.9	1.98
NP	1.7	1.9	1.7	1.7	2.2	9.2	1.84
NK	1.8	2.0	2.0	1.9	2.5	10.2	2.04
NPK	1.6	1.8	1.9	1.9	2.4	9.6	1.92
Control	1.6	1.8	1.9	1.9	2.4	9.6	1.92
Totals	8.3	9.9	9.5	9.4	11.4		9.70
Averages	1.66	1.98	1.90	1.88	2.28		1.94

The calculation of DRIS indices (24) from foliar nutrient concen- trations with the aid of diameter measurements was not made at the beginning of the experiment and did not serve as a guide for the fertilizer treatments (Table 11). The indices served, however, to show which nutrients were limiting after some of the fertilizer treatments. The indices were not calculated for the treatment including CaN_{674}. Although this treatment readily supplied available N, it required high levels of fertilizer and contributed an excess of Ca considered to be detrimental to sugar yield.

Dominant trees treated with U_{224} + TSP_{448} (Table 11) had limiting levels of N and Mg in 1977. However, because of the increase in diameter growth (Table 3), the demand for N in these trees by 1980 continued to increase, while the demand

TABLE 7

Analysis of Variance of Direct Effects and Interactions of Fertilizer Treatments on Sugar Yields and Concentrations Based on Refractometer Readings Over a 5-Year Period.

Source	DF	MS	F	Error Probability (Significance)
Sugar Yields				
Treatments	4	2,314,905.79	578,726.45	2.67	0.03*
Crown Classes	2	21,186,946.16	10,593,473.08	48.90	0.00***
Replications	2	1,071,860.51	535,930.25	2.47	0.09
Treats x Classes	8	1,668,832.82	208,604.10	0.96	0.47
Treats x Reps	8	6,972,231.67	871,528.96	4.02	0.00***
Classes x Reps	4	2,340,915.89	585,228.97	2.70	0.03*
Treats x Classes x Reps	16	6,265,637.39	391,602.34	1.81	0.03*
Error	180	38,990,489.20	216,613.83		
Total	224	80,811,819.43			
Sugar Concentrations				
Treatments	4	0.74	0.18	1.50	0.20
Crown Classes	2	1.62	0.81	6.57	0.00**
Replications	2	2.88	1.44	11.65	0.00***
Treats x Classes	8	1.13	0.14	1.14	0.34
Treats x Reps	8	3.67	0.46	3.70	0.00***
Classes x Reps	4	2.95	0.74	5.96	0.00***
Treats x Classes x Reps	16	4.83	0.30	2.44	0.00**
Error	180	22.27	0.12		
Total	224	40.09			

* Significant at 5% level
** Significant at 1% level
*** Significant at 0.1% level

for Mg had lessened slightly, possibly due to the balancing effect of the Ca uptake from triple superphosphate on foliar Mg. A suggested follow-up treatment would be $U_{224} + TSP_{224} + KCl_{112}$.

Codominant trees treated with $U_{224} + KCl_{224}$ had limiting levels of K, Ca and P in 1976. By 1977, only the demand for K had been met. The demand for Ca had lessened somewhat, but the demand for P had increased greatly. By 1980,

TABLE 8

Comparison of Refractometer Readings of Percentage Sugar Concentrations in Small Sap Samples from Awl Perforations with readings from 1-Litre Sap Samples from Buckets after Stirring.

Tree No.	March 8, 1979 Air temperature +3°C 1035 to 1245 hours Refractometer temp. 20°C		March 21, 1979 Air temp. +8°C 1035 to 1245 hours Ref. temp. 20°C		March 28, 1979 Air temp. 0°C 1035 to 1245 hours Ref. temp. 20°C		Averages	
	Spot sample	Bucket sample	Spot sample	Bucket sample	Spot sample	Bucket sample	Spot	Bucket
2	3.6	1.4	2.5	2.3	1.8	1.6	2.63	1.77
3	2.5	1.2	2.7	1.9	1.9	2.0	2.36	1.70
5	3.6	1.4	2.0	2.3	1.8	2.8	2.47	2.17
7	3.4	1.8	2.7	2.4	2.3	3.2	2.80	2.47
8	1.9	1.8	2.6	3.0	2.0	1.9	2.17	2.23
10	4.9	1.8	2.4	2.1	2.2	2.5	3.17	2.13
11	2.2	1.5	2.5	1.9	1.9	2.1	2.20	1.83
12	2.8	1.4	2.5	2.2	1.9	2.3	2.40	1.97
14	2.5	1.7	2.3	2.0	1.9	2.4	2.23	2.03
15	5.4	2.0	4.3	2.4	2.5	3.0	4.06	2.47
16	2.9	1.4	2.0	1.9	3.5	2.2	2.80	1.83
18	1.6	1.1	2.0	1.7	3.0	1.6	2.20	1.47
20	2.4	1.1	2.6	1.9	2.4	2.3	2.47	1.77
21	1.2	1.3	2.6	2.0	2.4	2.3	2.07	1.87
23	3.2	1.6	2.4	2.6	3.3	3.6	2.97	2.60
24	2.6	1.6	2.6	2.0	2.0	2.0	2.40	1.87
26	2.0	1.1	1.6	1.7	1.0	1.3	1.53	1.37
27	1.4	1.5	2.1	1.9	1.4	1.8	1.63	1.73
30	3.0	1.9	2.9	2.2	2.5	2.4	2.80	2.17
31	2.7	2.0	3.3	2.6	2.8	2.3	2.93	2.30
32	2.2	1.6	2.5	2.0	2.1	2.4	2.27	2.00
33	2.8	1.4	3.0	2.2	1.8	2.2	2.53	1.93
34	2.7	1.7	2.3	1.9	2.0	2.0	2.33	1.87
36	2.2	1.5	2.8	2.0	2.5	2.7	2.50	2.07
37	2.1	1.5	2.2	2.0	1.8	2.3	2.03	1.93
38	3.5	1.7	1.5	1.8	1.9	3.4	2.30	2.30
39	1.8	1.6	1.6	2.1	1.8	1.9	1.73	1.87
40	3.0	1.1	2.5	1.5	1.9	2.6	2.47	1.73
41	1.6	2.0	2.0	2.4	2.1	1.9	1.90	2.10
42	2.2	1.7	1.7	2.0	2.4	2.0	2.10	1.90
43	1.3	2.4	2.3	3.0	1.4	1.8	1.67	2.40
44	2.4	1.7	2.2	2.2	1.6	2.3	2.38	2.00
Averages	2.61	1.58	2.41	2.13	2.12	2.28	2.38	2.00

TABLE 9

Two-Way Analysis of Variance and "t-Test" of Effects of Fertilizer Treatments on Percentage Foliar Nutrient Concentration.

		F-ratio				
Source	DF	N	P	K	Ca	Mg
Treatments	4	13.39**	4.10	10.30**	0.30	0.81
Crown class	2	2.56	4.93*	4.83*	1.27	9.28**
Error	8					
		t-Test				
Treatments		N	P	K	Ca	Mg
NPK vs Cont.	2	6.145*	1.711	1.711	0.307	0.973
NK vs Cont.	2	3.632*	1.148	27.526***	0.224	0.350
NP vs Cont.	2	4.069*	2.489	0.629	1.004	0.031
NCa vs Cont.	2	8.461**	1.000	1.296	0.074	0.520
Significance:		F_{05} 4.46	F_{01} 8.65	t_{05} 2.920	t_{01} 6.965	

the demand for P was very great and a substantial demand for N had arisen. The demand for Ca had greatly decreased possibly because of increased root activity since there was a considerable increase in diameter growth after the treatment. A suggested follow-up treatment would be U_{224} + TSP_{448} + KCl_{122}.

Intermediate trees treated with U_{224} + TSP_{448} + KCl_{224} had limiting levels of P, Ca and Mg in 1977. By 1978, the P demand had lessened, the demand for Mg had almost vanished, but the demand for Ca had greatly increased. However, by 1980, the demand for P had become dominant and a small demand for N had arisen. Apparently an excess K was interfering with the uptake of P and to a lesser extent N. A suggested follow-up treatment would be U_{224} P + TSP_{448}.

Sap Nutrient Analyses: Analyses for sap nutrients before (March 30) and after (April 18) bud break of sugar maple for the 1979 sap season are shown in Table 12. The percentage increase in sap nutrients after bud break varied with the nutrient and the crown class.

TABLE 10

Average Percentage Starch Concentrations in Upper Crown Foliage of Sugar Maple Three Months After Start of Fertilizer Treatments.

Treatments	% Starch of oven dry weight of foliage			
	Dominants	Codominants	Intermediates	Averages
NCa	1.53	1.40	1.53	1.48
NP	1.51	1.33	1.35	1.40
NK	1.66	1.81	1.73	1.73
NPK	1.21	1.44	1.29	1.31
Control	1.45	1.47	1.45	1.46
Total	7.37	7.45	7.35	
Averages	1.47	1.49	1.47	1.48

"t-Test" Treatments	DF	"t"-values	t_{05}	t_{01}
NCa vs Control	2	0.551	2.920	6.965
NP vs Control	2	1.045		
NK vs Control	2	6.740*		
NPK vs Control	2	2.297		

TABLE 11

DRIS Indices Calculated from Foliar Nutrient Concentrations of Tapped Trees after Fertilizer Treatments.

Crown class	Treatment in 1976	Year	DRIS Indices				
			N	P	K	Ca	Mg
Dominant	U_{224} + TSP_{448}	1977	-1.1	+2.0	+1.5	+1.3	-3.7
		1978	+0.6	+6.5	-0.3	-4.0	-2.7
		1980	-9.9	+9.7	-0.6	+3.3	-2.5
Codominant	U_{224} + KCl_{224}	1976	+9.4	-2.1	-6.3	-5.7	+4.8
		1977	0.0	-7.9	+9.7	-1.9	+0.2
		1978	+2.3	-5.4	+9.3	-8.2	+1.9
		1980	-5.9	-11.1	+3.8	+6.6	+5.6
Intermediate	U_{224} + TSP_{448} + KCl_{224}	1977	+1.3	-3.8	+7.0	-3.3	-1.1
		1978	+8.5	-1.7	+1.0	-7.7	-0.5
		1980	-1.5	-8.4	+5.1	+2.3	+2.5

TABLE 12

Content of Sap Nutrients in Tapped Trees in Milligrams per Litre by Crown Classes Before and After Bud-Break.

Sampling date	N	Inc. (%)	P	Inc. (%)	K	Inc. (%)	Ca	Inc. (%)	Mg	Inc. (%)
Dominants										
March 30	9.2		1.9		51.7		68.6		3.9	
April 18	22.1	140	3.5	84	59.5	15	74.1	8	5.3	36
Codominants										
March 30	8.0		1.6		49.9		59.9		3.5	
April 18	22.2	177	3.4	89	58.2	17	74.4	24	5.1	46
Intermediates										
March 30	7.4		1.9		50.3		50.4		3.0	
April 18	24.7	235	3.2	68	56.3	12	70.5	40	4.9	63

Budgetary limitations did not permit studying the relation between sap nutrients and fertilizer treatments which would be a useful investigation. However, it was possible to show correlations of some sap nutrients in tapped trees with sap volume, sugar yield, foliar nutrient concentrations, and other sap nutrients (Table 13).

In Table 13, there was a positive correlation (R) at the 1% level of confidence of sap P, Ca and Mg with sap N, and a negative correlation of sap Ca and Mg with diameter growth. In dominant trees, there was a negative correlation of sap Ca and Mg with sap volume and sugar yield. This indicated that as the N fertilization was increased, the uptake of Ca and Mg was also increased, but an excessive uptake of Ca and Mg would reduce diameter growth, crown development and consequently sap volume. Also, an excessive uptake of Ca and Mg would increase the cost of syrup production by requiring a longer processing time to remove "sugar sand" (20), *i.e.*, Ca and Mg from the syrup solution. This emphasized the importance of controlling fertilizer applications so as to supply limiting nutrients while avoiding over-fertilization.

Relation of Tree Diameter, Crown Area and Crown Competition to Sugar Yield: Tapped trees on 100 m^2 sub-plots having the greatest basal area of competing trees (Table 14) did not always have the lowest sugar yield. It was suspected that crown

TABLE 13A

Significant Correlations (R) of Sap Nutrients with Other Response Measurements Regardless of Crown Class.

Sap nutrients	Sap P	Sap Ca	Sap Mg	Foliar N	Foliar K	Foliar Ca	Diameter increase
N	1%**	1%	1%				
K				5%			
Ca			1%		-5%	5%	-1%
Mg					-5%		-1%

** Significance of R. Foliar nutrient concentrations as at mid-July, 1976. Diameter increases at the end of the 1978 growing season. Sap nutrients as on April 18, 1979.

TABLE 13B

Significant Correlations (R) of Sap Nutrients with other Response Measurements by Crown Classes.

Crown Class	Sap nutrients	Sap P	Sap Mg	Sugar yield	Sap volume
Dominants	Ca		1%**	-1%	-1%
	Mg			-1%	-1%
Codominants	Ca		1%		
Intermediates	N	1%			
	Ca		1%		

** Significance of R. Sugar yield and sap volume were for the 1979 collecting season. Sap nutrient levels were for April 18, 1979.

area had a greater effect than root competition on sugar yield, although there was no direct correlation between crown area and sugar yield. However, after the crown areas of the tapped tree and competing trees were measured and the area of overlap of the competing trees on the tapped tree was subtracted from the crown area of the tapped tree, the residual crown area of the tapped tree correlated with the sugar yield of that tree (Table 15). This showed that the measurement of

TABLE 14

Fertilizer Treatments, Competition Factors and Sugar Yields of Tapped Trees by Crown Classes.

Treat.	Dominants		Codominants		Intermediates	
	Avg. C/T*	Avg. 1981 sugar yield (grams)	Avg. C/T	Avg. 1981 sugar yield (grams)	Avg. C/T	Avg. 1981 sugar yield (grams)
NCa	1.31	1608	2.75	1139	7.74	925
NP	2.31	1936	2.53	1627	6.86	930
NK	1.77	1871	2.54	1250	5.46	858
NPK	2.55	2235	2.79	1332	4.55	922
Control	2.38	1827	2.65	919	2.77	871
Avg.	2.06	1895	2.65	1253	5.47	901

*C/T = $\frac{\text{Basal area of competing trees}}{\text{Basal area of tapped tree}}$

residual crown area was a more reliable way (other factors being equal) of selecting crop trees than dependence upon tree diameter or crown width, since it had the additional advantage of making it convenient to mark for removal those trees competing the most with the crop trees. The effect of crown area on sugar yield was demonstrated by silhouettes of tapped trees which were drawn from photos taken during the dormant season. These silhouettes showed how yield and to a lesser extent sugar concentration varied with crown size. Furthermore, sketches in plan and elevation of crop trees showed how the effect of crown size was modified by competing crowns so that the residual crown area could be more closely related to sugar yield and concentration (3).

DISCUSSION AND RECOMMENDATIONS

Although the maple syrup industry supplies a unique product having an almost limitless world market, not many producers are willing to invest as heavily in methods of increasing sap production as in processing the sap into maple syrup. This perhaps is owing to the difficulties of trying to overcome the many hazards, unfavourable weather, insect infestations, fungal diseases and aerial pollution, which are disruptive to starch storage and so reduce sugar production. However, these hazards are common to all agricultural crops and are accepted and compensated for by the more persistent syrup producers who already have a large investment in the industry. They reason that even if one sap collecting season is

TABLE 15

Correlations of Sugar Yields and Crown and Bole Dimensions of Sugar Maple

Comparisons	R-Value
Annual sugar yield vs residual crown area	.689
Annual sugar yield vs residual crown width	.638
Annual sugar yield vs DBH of tapped tree	.620
Annual sugar yield vs basal area of tapped tree	.639

Significance n = 21; DF = 19; $R_{.05}$ = .433; $R_{.01}$ = .549

shortened by adverse weather, the sap that would have been collected in that season is not lost, but will contribute to increased crown development and more sugar production in the following years. The effects of the other hazards may be mitigated by increased silvicultural activity.

It is not expected that entrepreneurs who do not already own woodlots and farm equipment would invest heavily in silvicultural activities. However, when established farmers with a long tradition of investment in collecting and processing equipment, are doubtful of remaining in the industry, they should consider the spin-off advantages to the community as a whole as well as the need to salvage the equipment investment already made. For these farmers, it is unlikely that the practice of clear-cutting the sugar bush after one or more poor collecting seasons would earn more revenue than the continuation of maple sap production, since tapped trees have limited use for lumber. On the other hand, if diseased trees, damaged trees and trees offering the most crown competition to crop trees are gradually removed, their places would soon be occupied by young growth less susceptible to damage from insects, disease and air pollution.

Although a farm woodlot intended for maple syrup production should be managed differently from one intended for lumber production, the same care in marking and protecting crop trees should be shown (4,5). In either case, access roads must be located to avoid blocking drainage or damaging tree roots. However, the thinning plans should differ. For syrup production, the thinnings should reduce the crop trees to about 240/ha (12). The thinnings should be gradual so as to reduce crown competition to crop trees without exposing them too abruptly to sunscald.

Besides thinning and cleaning, the woodlot manager can further reduce growth hazards by inspecting the woodlot during the dormant season. He can record the number of egg masses of known defoliating insects to anticipate infestations and take remedial action before extensive foliage damage occurs. He can sample the soil to identify the soil series and have soil samples analyzed to detect nutrient deficiencies and the possible need for fertilization. The history of the woodlot can be of assistance in this respect. Nutrient deficiencies can be suspected on sugar maple woodlots from which trees and sap nutrients have been removed for 100+ years and there is evidence of aerial pollution and soil erosion.

In planning a fertilization program, it is unlikely that the use of a single fertilizer will provide sufficient growth response. A system of monitoring the effectiveness of the fertilizer is needed using growth measurements and foliar or sap analysis. After fertilization, the response in syrup yield may be delayed until the crop tree crowns have expanded, provided there is available space for that expansion.

In fertilizing, care must be shown for levels of Ca and Mg, which may buffer the effects of acid rain, but in excess may be a drawback to tree growth and sugar yield. Where NP is limiting and Ca is not, fertilization with ammonium phosphate may be preferable to urea + triple superphosphate to avoid adding Ca in the latter combination. In woodlots where the soil is below pH 5.5, and Ca and N are in demand, calcium nitrate may be a good source of both nutrients. However, Ca and Mg levels in NPK fertilizer must be carefully controlled because of the antagonism with K, which relates so well to starch storage and sugar yield.

In fertilization programs, the practicability of treating crown classes differently should be considered. Large dominant trees having occupied a site for a long time, are more likely to have reduced the supply of available nutrients than smaller codominant and intermediate trees. In fertilizing, broadcasting with heavy equipment may be injurious to crop trees and a cause for soil erosion. Preferably, application by hand of prepackaged fertilizer in small annual dosages in plastic bags for each tree in each crown class, would be more economical of fertilizer especially when crop trees are not closely grouped and one wishes to avoid fertilizing non-crop trees. Because the fixation of nutrients such as P varies with the soil type, dosages of fertilizer P may need to be higher than a general soil analysis may indicate is needed. However, care must be taken not to overfertilize, because when nutrients are added to the soil in excess of need, the response may

be less than that of the control.

In any long-term fertilization program, the calculation of DRIS indices from foliar nutrient concentrations will determine which limiting nutrients should be included in the fertilizer applications. If the manager is not familiar with this technique, he can be informed through training sessions conducted by a sugar ample specialist. Eventually, the chemical analysis of foliage may be the only part of the technique the manager would not wish to carry out himself.

Besides fertilization, a further improvement in sugar production can be obtained by marking and cultivating those trees having the highest sugar concentration so these are not removed in thinning operations. For these selections, the refractometer may be a more accurate instrument than the hydrometer for measuring small quantities of sap and relating percentage sugar concentration to temperature. This should avoid the bias of concentration readings made during very low temperatures.

In addition to sugar concentration, the manager should be concerned with trying to improve sap collection. The use of a paraformaldehyde pill has been recommended (10) to be inserted in the spile hole to improve sap flow, but taphole infections have been reported after the use of this pill. However, it has been found that these infections occur most often in old trees with declining growth in which the tapholes have been placed close together. Although every taphole is a potential infection port (as are increment borings for growth measurements) most heal over in vigorous trees in the growing season following tapping. It is only when there is a delay in healing due to poor growth that fungal infections are likely to start.

An important concern in sap collection arises from the gnawing damage by squirrels on polyethylene tubing. Sometimes this damage is prevented by using dark-colored rather than light-coloured tubing to hide the movement of the sap bubbles which seem to attract squirrels. Where the squirrel damage persists, the removal of nut-bearing trees and the introduction of predator birds may give control.

Although the long-term maintenance of sugar maple woodlots must compete for attention with the many other activities of the farmer, some have accepted this as a challenge to their ingenuity. If they are able to manage their woodlots silviculturally as well as they manage their costly collecting and processing equipment, the maple syrup industry may continue to flourish.

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